Technologies for Sustainable Buildings: Some Recent Hong Kong Research

Jin-Guang TENG 滕锦光
Director, Research Institute for Sustainable Urban Development,
Dean, Faculty of Construction and Environment &
Chair Professor of Structural Engineering
The Hong Kong Polytechnic University

Outline

- Introduction
- Research Institute for Sustainable Urban Development (RISUD)
- Virtual construction
- Energy efficiency
- Renewable energy
- Recycling of materials
- Indoor air quality

Faculty of Construction and Environment

- Department of Building and Real Estate
  建築及房地產學系
- Department of Building Services Engineering
  屋宇設備工程學系
- Department of Civil and Environmental Engineering
  土木及环境工程學系
- Department of Land Surveying and Geo-informatics
  土地測量及地理資訊學系

Overview

- A history of 75 years
- Over 4600 students
- Over 110 academic staff members at Lecturer and above levels
- About 270 research students
- About 220 research staff
- Receives around 40% of construction-related research grants from the Research Grants Council of Hong Kong

* As of January 2012

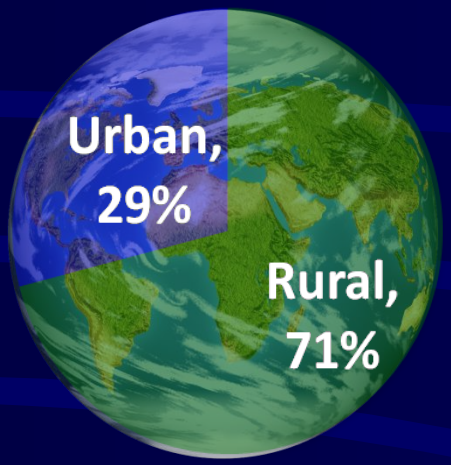
Research Grants in Construction-Related Disciplines Won by FCE from the Hong Kong Research Grants Council

- 2012/2013, 26 out of 67 grants, 39%
- 2011/2012, 20 out of 46 grants, 43%
- 2010/2011, 17 out of 40 grants, 43%
- 2009/2010, 21 out of 50 grants, 42%
- 2008/2009, 37 out of 79 grants, 47%
- 2007/2008, 25 out of 59 grants, 42%
- 2006/2007, 37 out of 86 grants, 43%
- 2005/2006, 28 out of 66 grants, 42%
- 2004/2005, 33 out of 74 grants, 45%

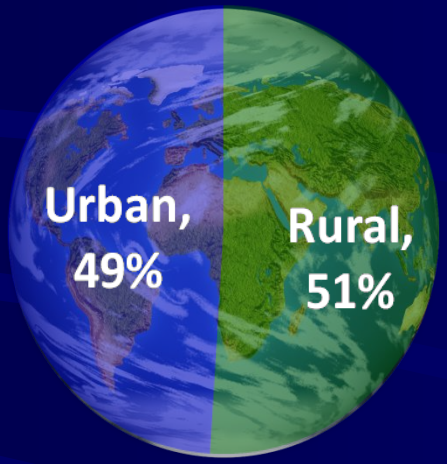
Outline

- Introduction
- Research Institute for Sustainable Urban Development (RISUD)
- Virtual construction
- Energy efficiency
- Renewable energy
- Recycling of materials
- Indoor air quality

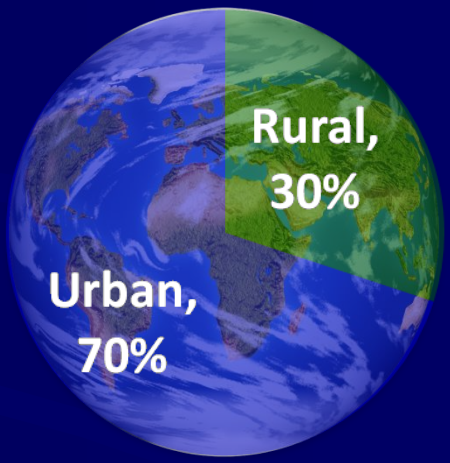
Facts of Urbanization



1950



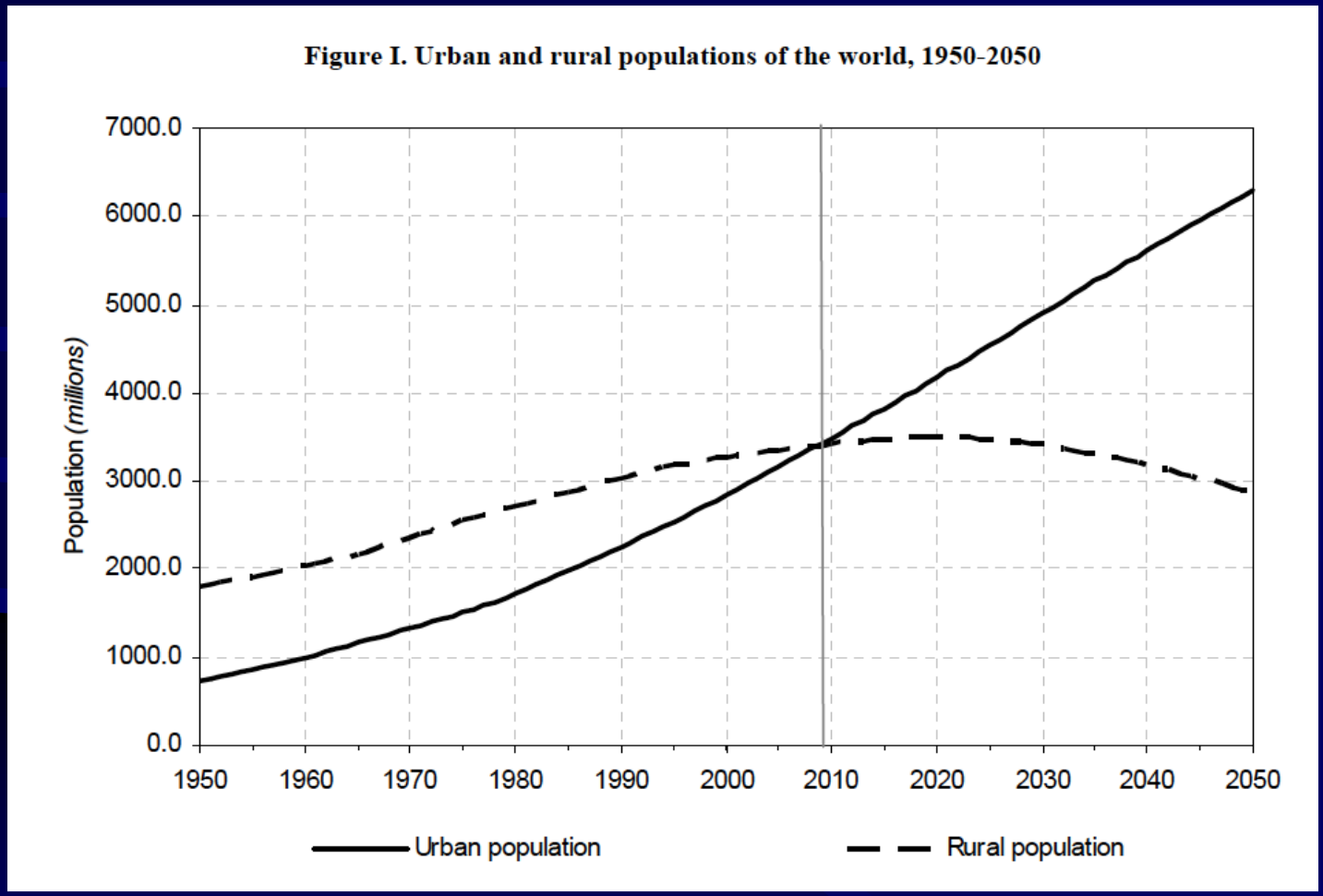
2007



2050

(United Nations Department of Economic and Social Affairs/Population Division, 2007)

Facts of Urbanization



Source: UN (2009) World Urbanization Prospects: The 2009 Revision Population Database

Sustainable Urban Development :
A major focus of the Faculty and PolyU

Opportunities for Hong Kong

- ✓ Hong Kong is a unique model of high-density cities characterized by high-rise residential blocks
- ✓ Hong Kong is ahead of the Chinese mainland in urbanization by at least two decades
- ✓ Most large cities in the mainland are becoming like Hong Kong
- ✓ Hong Kong's dense urban environment is a living laboratory for R & D
- ✓ Examples of Hong Kong's areas of opportunity:
  - Public transport systems
  - GPS navigation of vehicles
  - Management of underground assets

network.nationalpost.com

Opportunities for PolyU

Our strengths:

As explained earlier + strengths in other Faculties

Our vision:

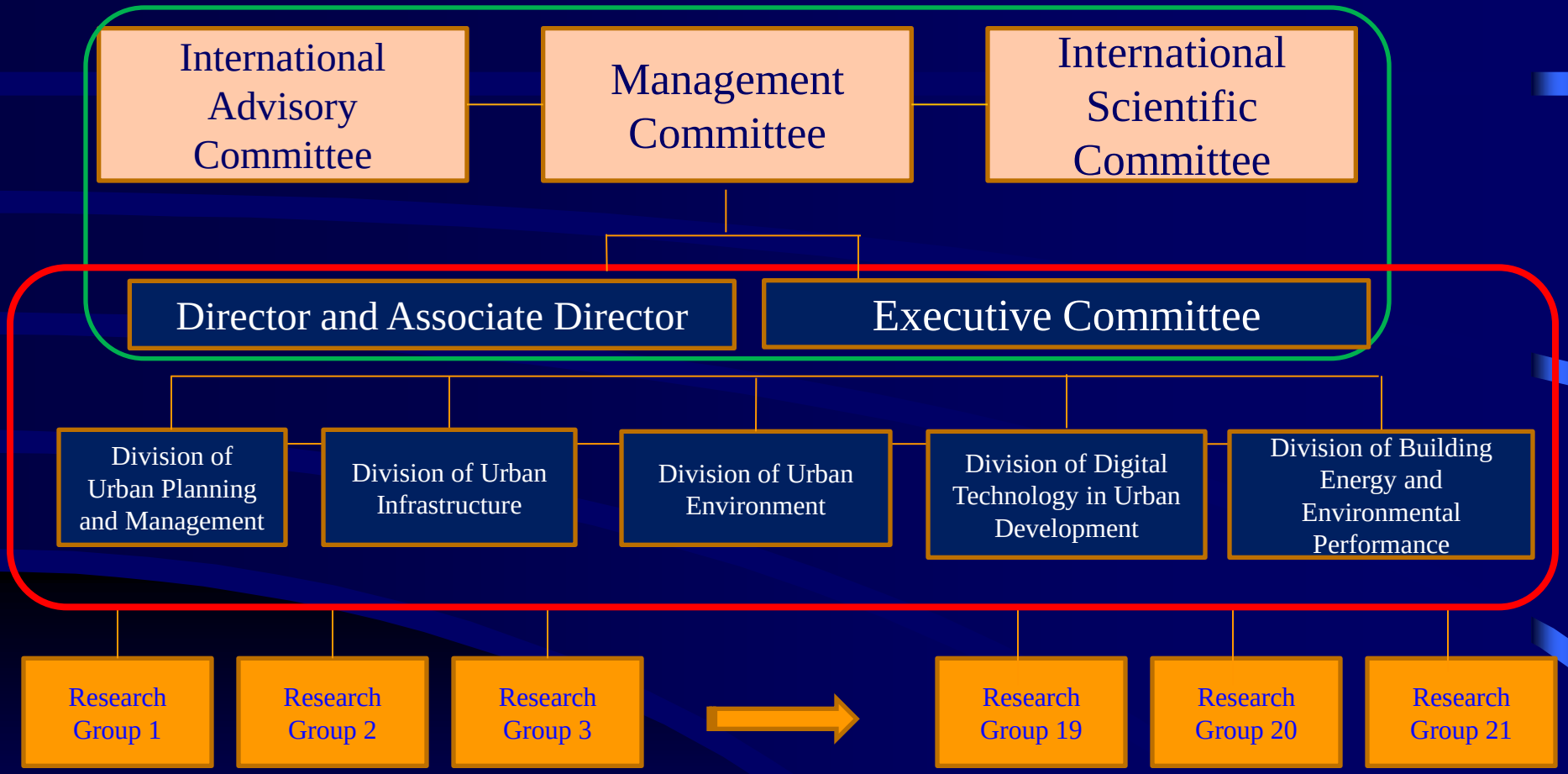
To be an international centre of excellence in teaching, research and technology transfer in the area of sustainable high-density urban development

http://leadership.uoregon.edu/upload/images/hongkong.jpg

- ✓ **Research Institute for Sustainable Urban Development**

  established in January 2012 by PolyU

Research Institute for Sustainable Urban Development



Innovative Solutions for Sustainable Cities

Divisions and Research Groups

Urban Infrastructure
- Construction Safety
- High-speed Railway Safety
- Infrastructural Monitoring
- Sustainable Materials and Structures
- Urban Geo-Hazards

Urban Planning and Management
- Sustainable Land Use
- Sustainable Transportation Systems
- Urban Housing Policies
- Urban Infrastructure Planning

Urban Environment
- Regional Air Quality
- Sustainable Waste Management
- Urban Ecosystems
- Urban Noise Mitigation

RISUD

With a coherent theme of Sustainable Urban Development

Building Energy and Environmental Performance
- Building Energy and Automation
- Indoor Air Quality
- Renewable Energy
- Urban Micro-Environment

Digital Technology in Urban Development
- Geo-spatial Technology in Urban Development
- Management of Underground Utilities
- Urban Navigation and Mobility
- Virtual Construction

Some Initial Focus Areas

- Air quality
- Space creation and reuse
- Solid waste management
- Urban health
- Urban mobility
- Building energy technology
- Underground asset management
- Life-cycle performance
- High-speed railway technology

Key Characteristics of RISUD

- ✓ Integration of expertise for major and /or multi-disciplinary research projects or programmes
- ✓ High-impact solutions for pressing socio-economic problems are emphasized
- ✓ Securing of individual grants and publication of papers are not the direct focus of the RI although they will be natural products of the RI's activities.

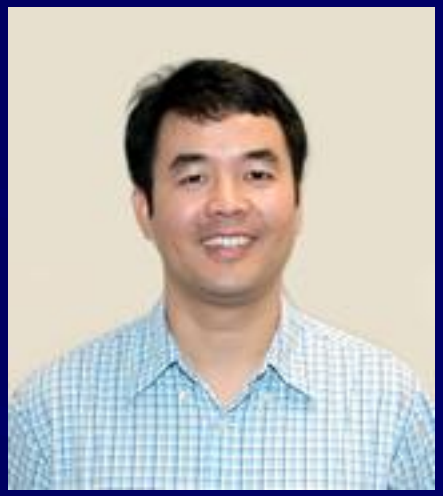
Outline

- Introduction
- Research Institute for Sustainable Urban Development (RISUD)
- Virtual construction
- Energy efficiency
- Renewable energy
- Recycling of materials
- Indoor air quality

Construction Virtual Prototyping Technology

Virtual Construction Research Group

- Construction Virtual prototyping (CVP) is a digital mock-up (3D model) of the construction process on the computer
- It is capable of simulating the entire construction process with actual data
- Building a structure first on the computer before building a real one!



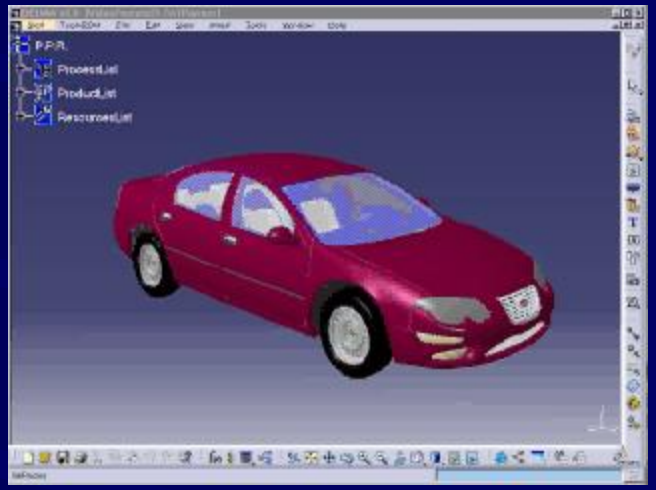
Group leader: Professor Heng Li

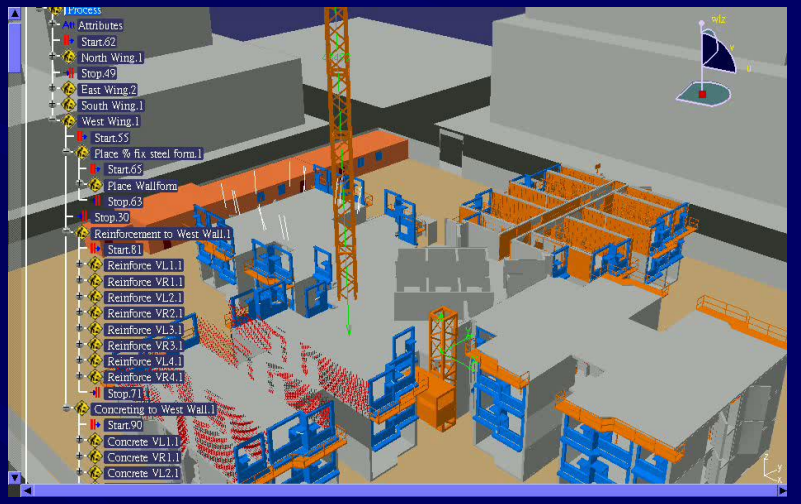
Current Situation of Construction management

- About 20-30% of the total cost is the 'management cost'
- Largely a trial-and-error process which leads to an additional cost of about 12-22% due to design errors, constructability, safety, and other risks
- Management focuses on reactive/remedial actions

Why Construction Virtual Prototyping?

- We do not have a fixed production line where the productivity is dominated by the speed of machines
- We do not have an effective platform to capture and re-use knowledge
- We cannot try things out before construction commences on site





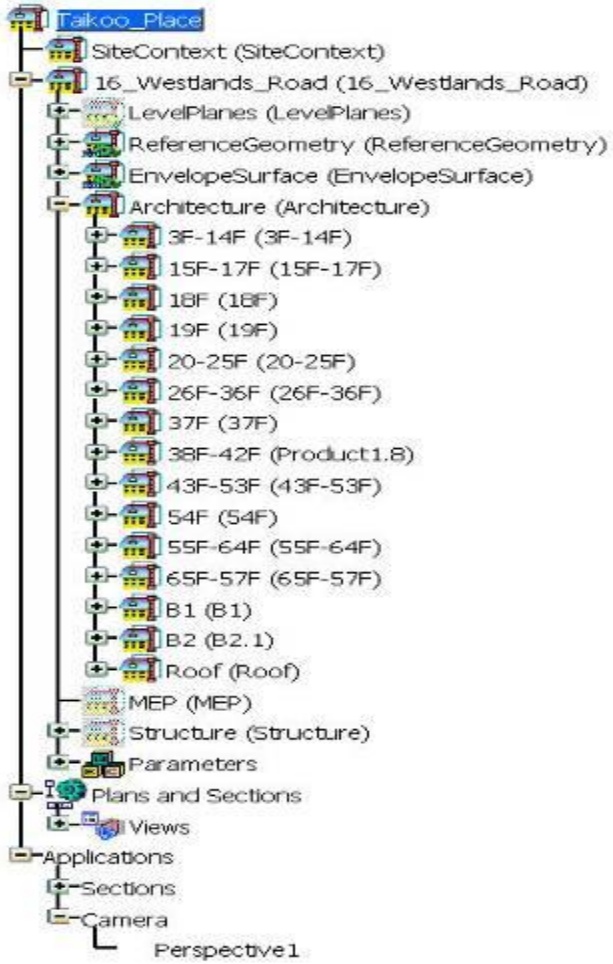
Why Construction Virtual Prototyping?

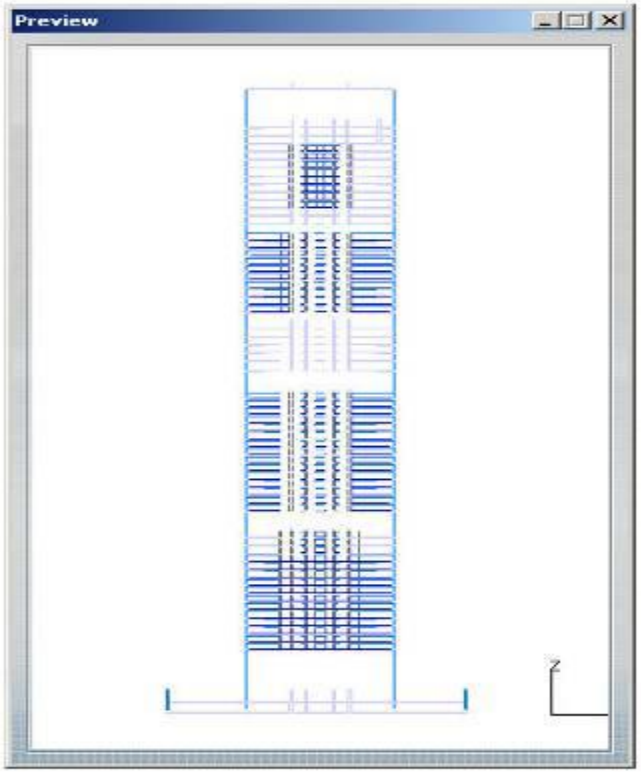
- Reduce uncertainty in construction planning
- Improve communication and coordination of works
- Reduce design errors
- Perform environmentally-friendly construction

Case Study: One Island East Project
-collaboration with Gammon Construction

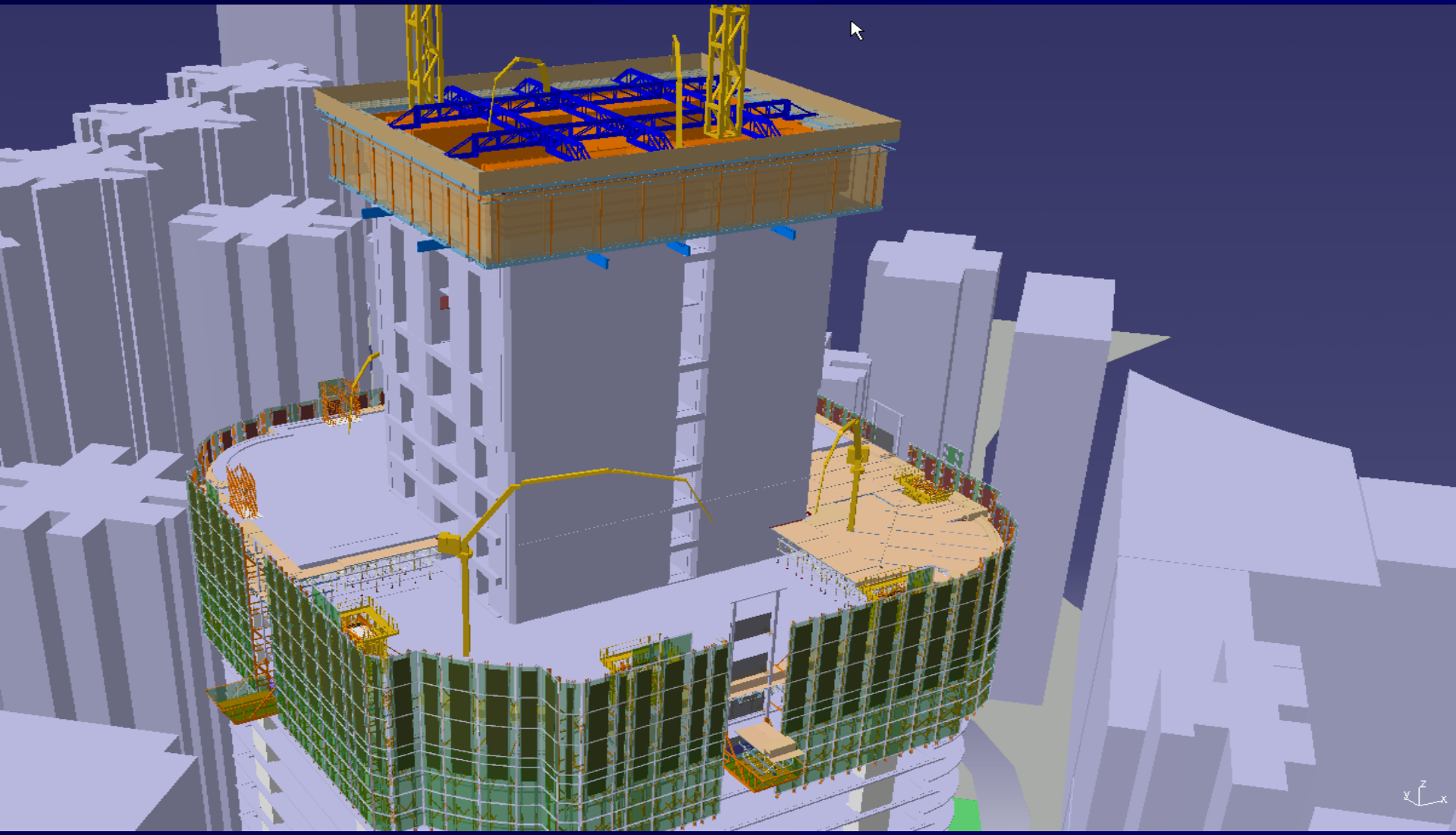
- 76-storey commercial building in Hong Kong island
- It required 2 years of construction time
- Over 2,000 workers worked on the project

3D Model

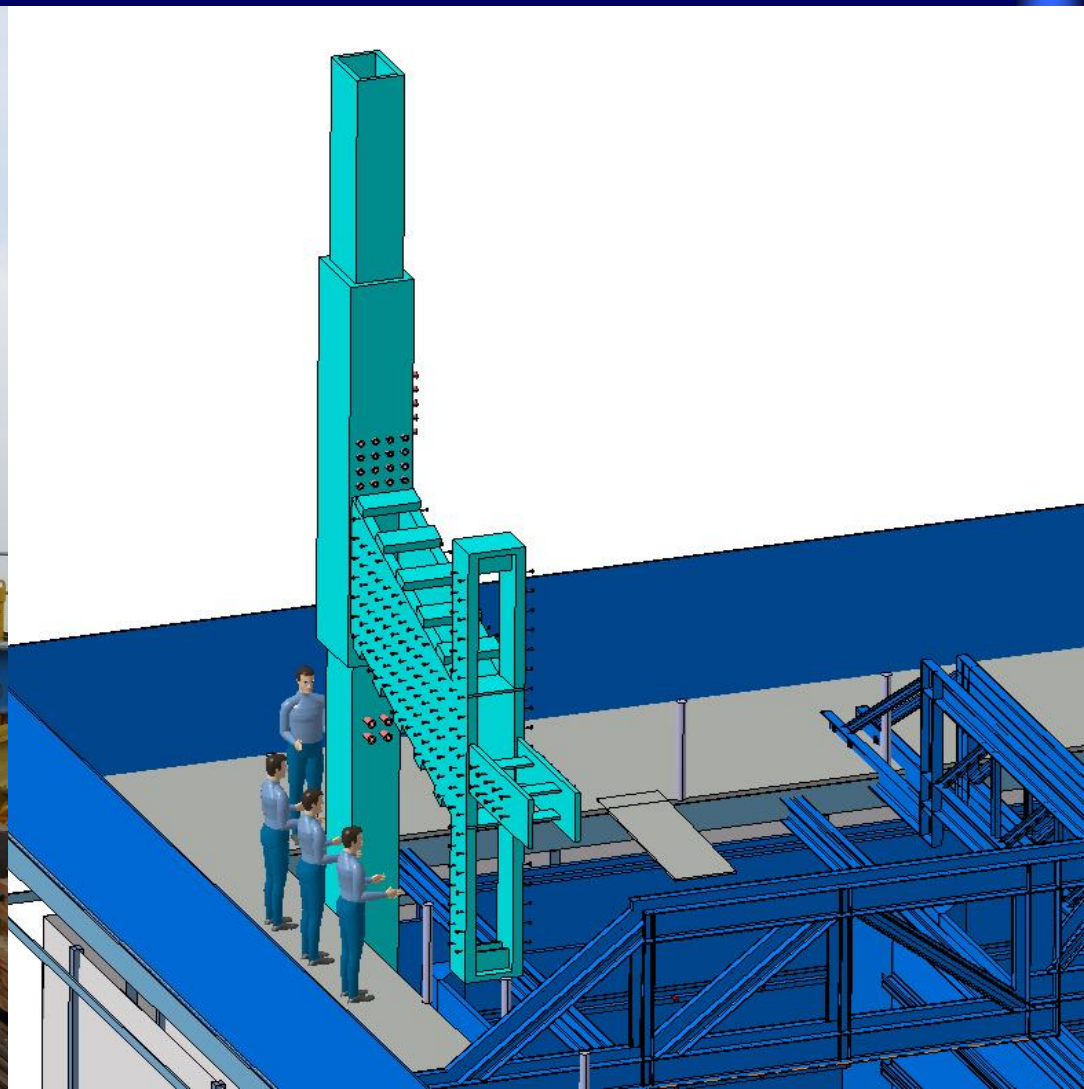

Taikoo_Place
SiteContext (SiteContext)
16_Westlands_Road (16_Westlands_Road)
LevelPlanes (LevelPlanes)
ReferenceGeometry (ReferenceGeometry)
EnvelopeSurface (EnvelopeSurface)
Architecture (Architecture)
3F-14F (3F-14F)
15F-17F (15F-17F)
18F (18F)
19F (19F)
20-25F (20-25F)
26F-36F (26F-36F)
37F (37F)
38F-42F (Product1.8)
43F-53F (43F-53F)
54F (54F)
55F-64F (55F-64F)
65F-57F (65F-57F)
B1 (B1)
B2 (B2.1)
Roof (Roof)
MEP (MEP)
Structure (Structure)
Parameters
Plans and Sections
Views
Applications
Sections
Camera
Perspective1


Preview

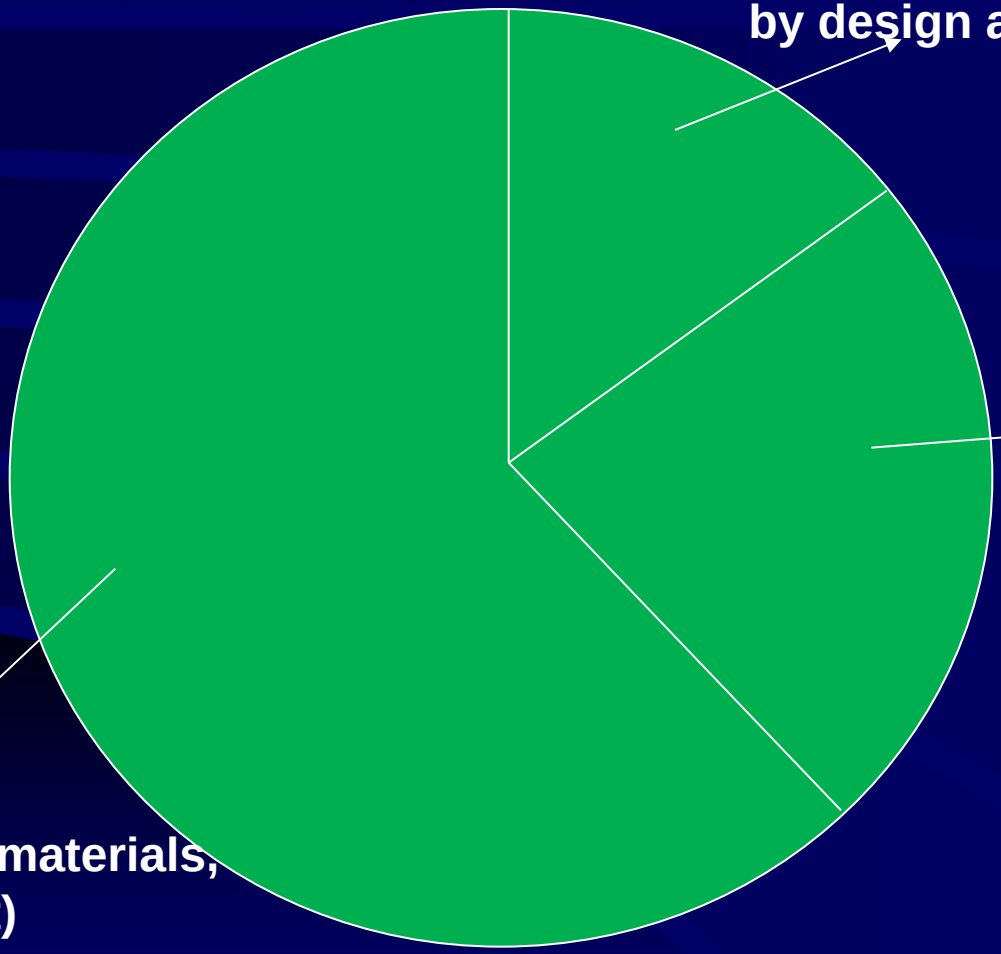
Simulation Of Site Operations



Real Situation versus Construction Virtual Prototyping



Current Project Cost Distribution

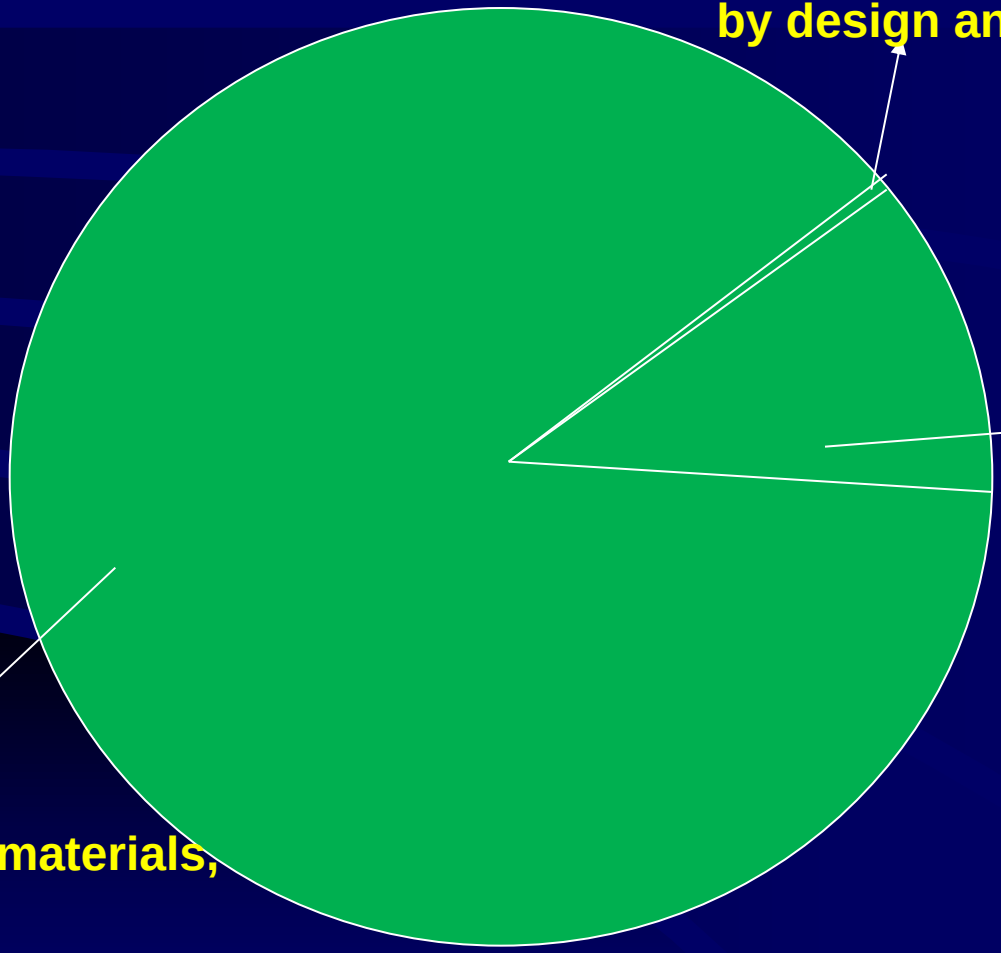


12 to 22% rework induced
by design and construction errors

25% overheads and
management costs

Direct costs (materials,
Labor & plant)

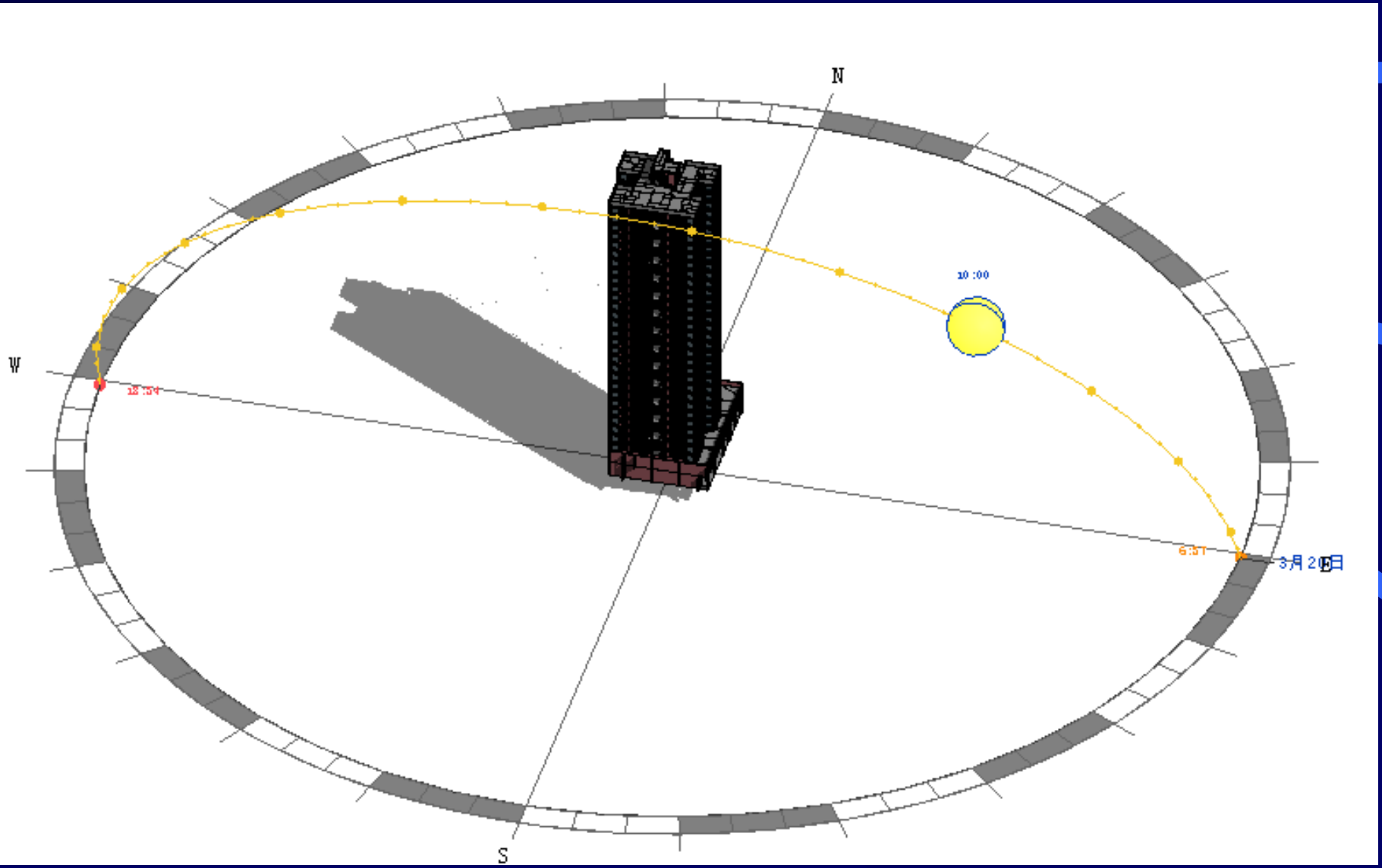
A Better Cost Distribution



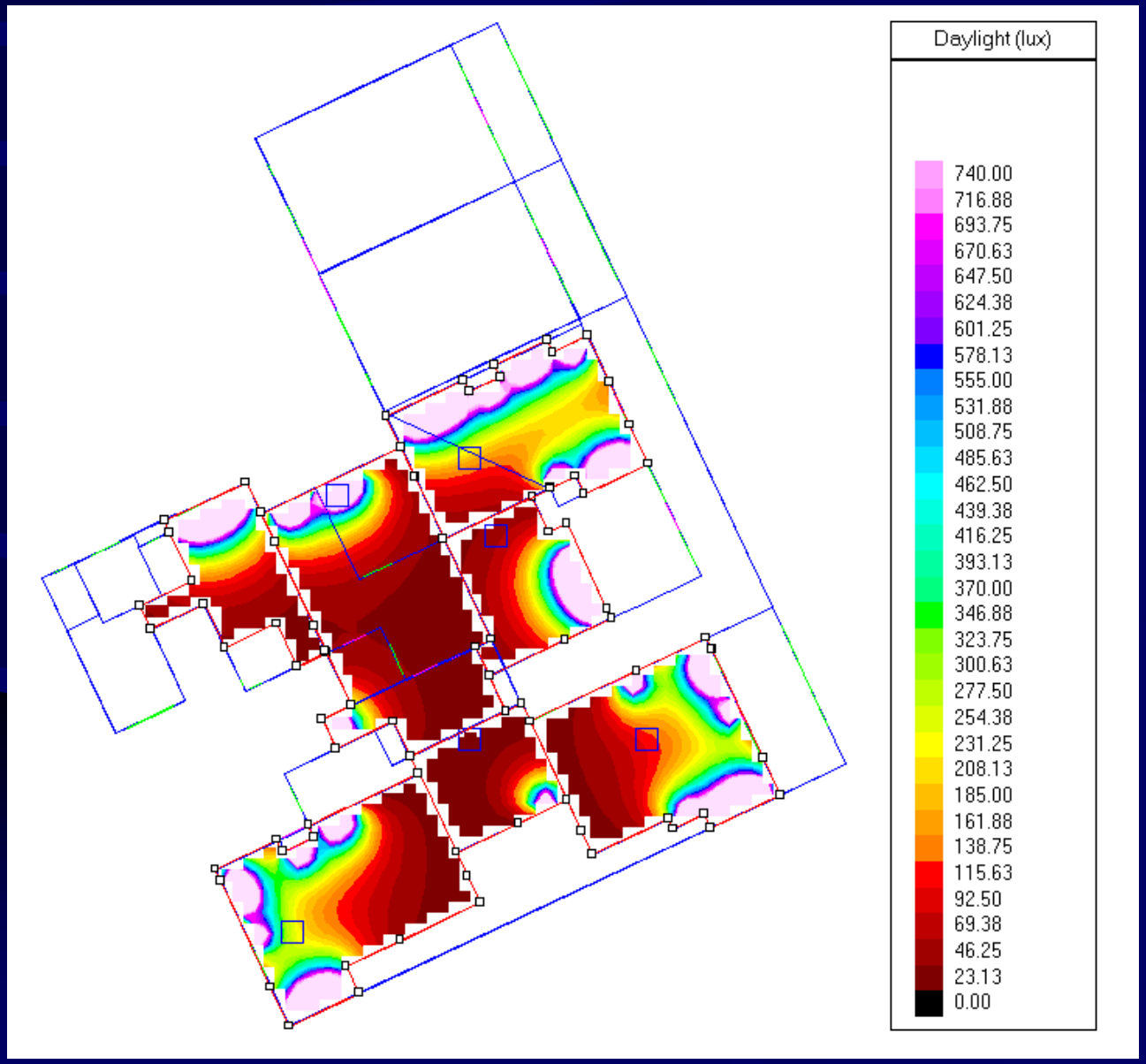
Nicro-Environment Analysis using BIM

- ✓ Wind: Cladding and structural loads, pedestrian level comfort, natural ventilation, energy production.
- ✓ Solar: Daylighting, solar heating, cooling load reduction, energy production and conservation.
- ✓ Temperature and Humidity: Natural ventilation, thermal comfort.
- ✓ Noise, Vibration & Acoustics: Sound and vibration isolation (external and internal), performance of acoustically sensitive spaces.
- ✓ Air Quality: Exhaust re-entrainment, ambient pollution levels.
- ✓ Air Distribution: Thermal comfort, indoor air quality, condensation control, smoke management.
- ✓ View: View from your window

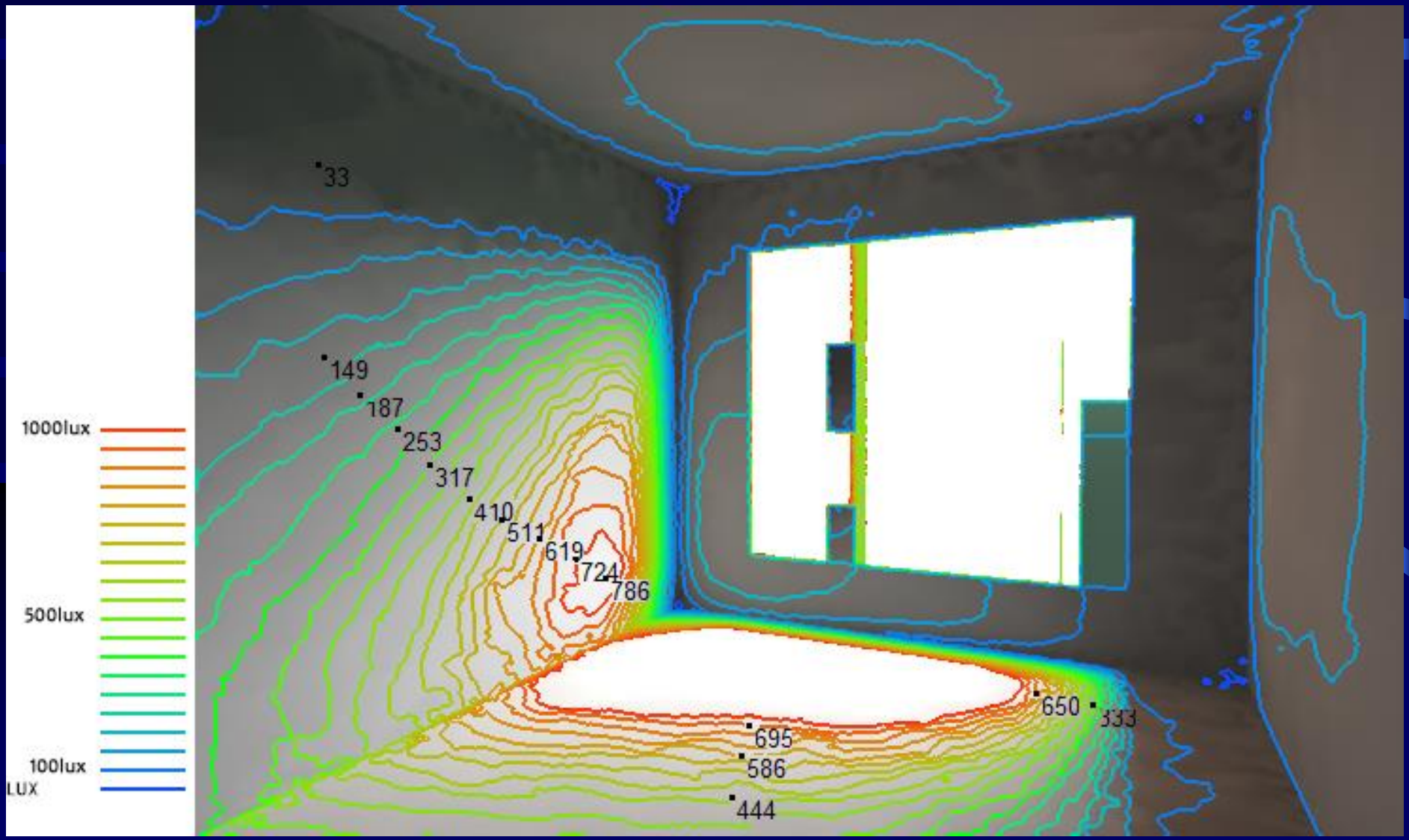
Daylight Analysis using BIM



Daylight Analysis of the 10th Floor

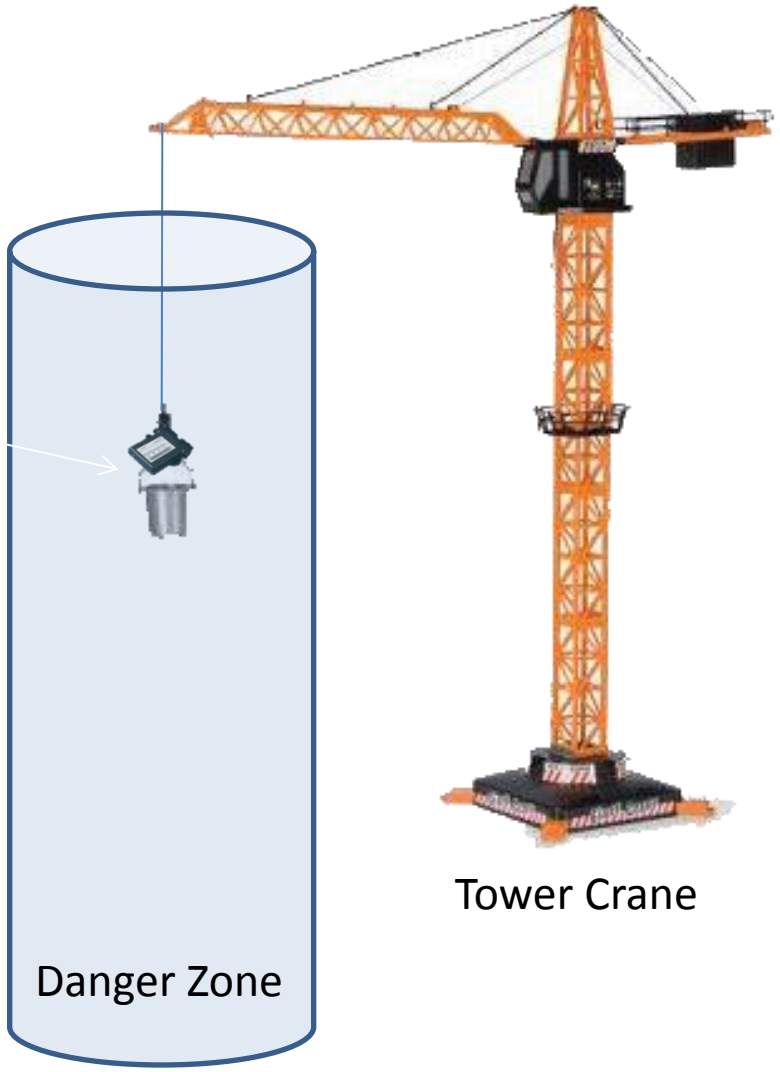


Daylight Analysis of the Main Bedroom



On-site Safety Management

When the worker walk into the danger zone, and the Proactive Construction Management System (PCMS) will alert tower and operator



Outline

- Introduction
- Research Institute for Sustainable Urban Development (RISUD)
- Virtual construction
- Energy efficiency
- Renewable energy
- Recycling of materials
- Indoor air quality

Intelligent Building Life-cycle Diagnosis/Commissioning and Optimization

Research Group for Building Energy and Automation

International Commerce Centre: A Collaborative Project with Sun Hung Kai Properties Ltd

PolyU's roles in the project:

- Independent Energy Consultant (Independent Commissioning Agent)
- Development of an HVAC Energy Optimization System (EOS) and Energy Performance Diagnosis System (EPDS)

Group leader:
Prof. Shengwei Wang

Outline

- Introduction
- Research Institute for Sustainable Urban Development (RISUD)
- Virtual construction
- Energy efficiency
- Renewable energy
- Recycling of materials
- Indoor air quality

Renewable Energy Technologies for Buildings

Renewable Energy Research Group

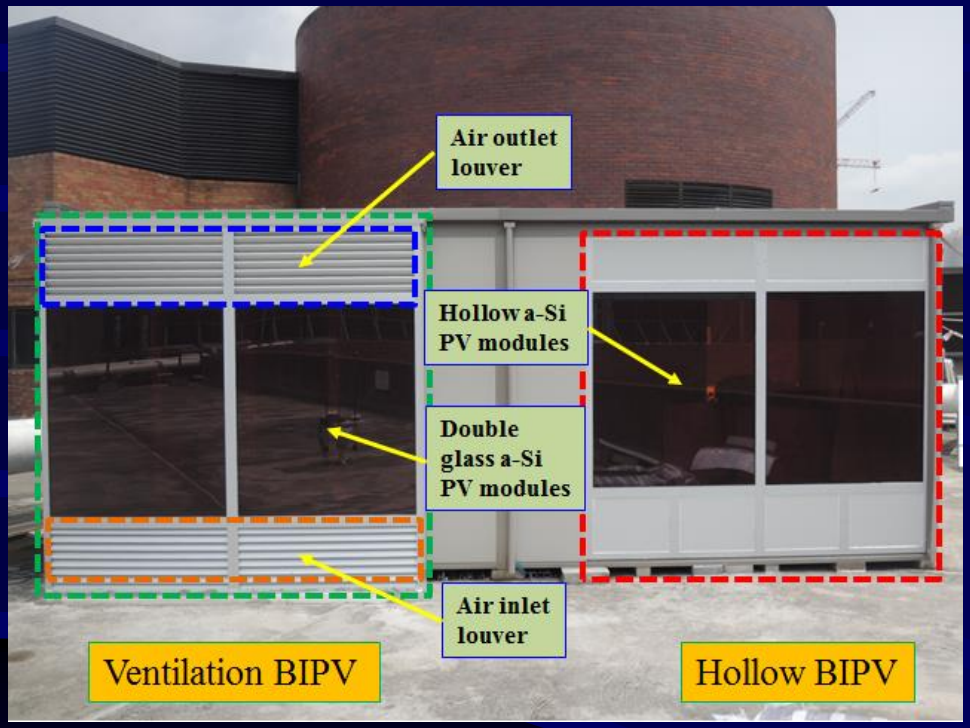
Group Leader:

Prof. Hong-xin YANG

Building-integrated Photovoltaics (BIPV)

- ✓ Optimal design of various BIPV claddings
- ✓ Simulating and predicting their dynamic power performance
- ✓ Life-cycle environmental payback assessment
- ✓ Thermal performance of BIPV claddings & its impacts on building energy consumption
- ✓ Impacts of weather conditions on their power output

Ventilated Building Integrated Photovoltaic Claddings (V-BIPV)

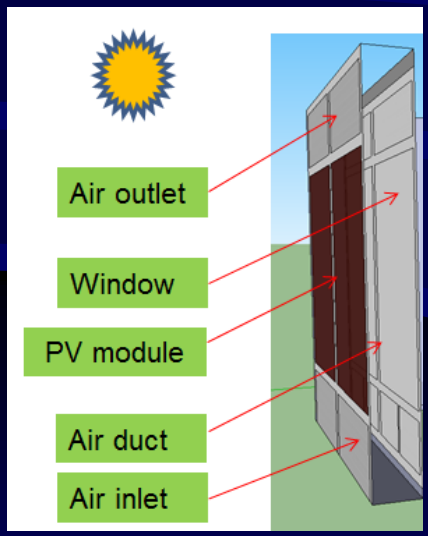


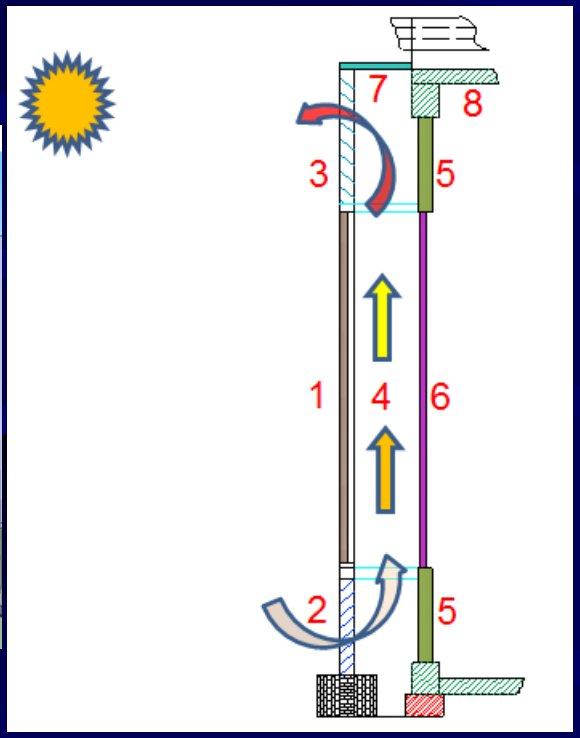
- ✓ The left one - ventilation BIPV cladding (V-BIPV).
- ✓ The right one - hollow BIPV cladding, directly substituting traditional glazed window.

The V-BIPV not only reduces the heat gain of the building envelope, but also increases the energy conversion efficiency of the PV modules by decreasing their operating temperature.

Ventilated Air Duct for V-BIPV

An air duct is installed between the PV modules and the south facing window.

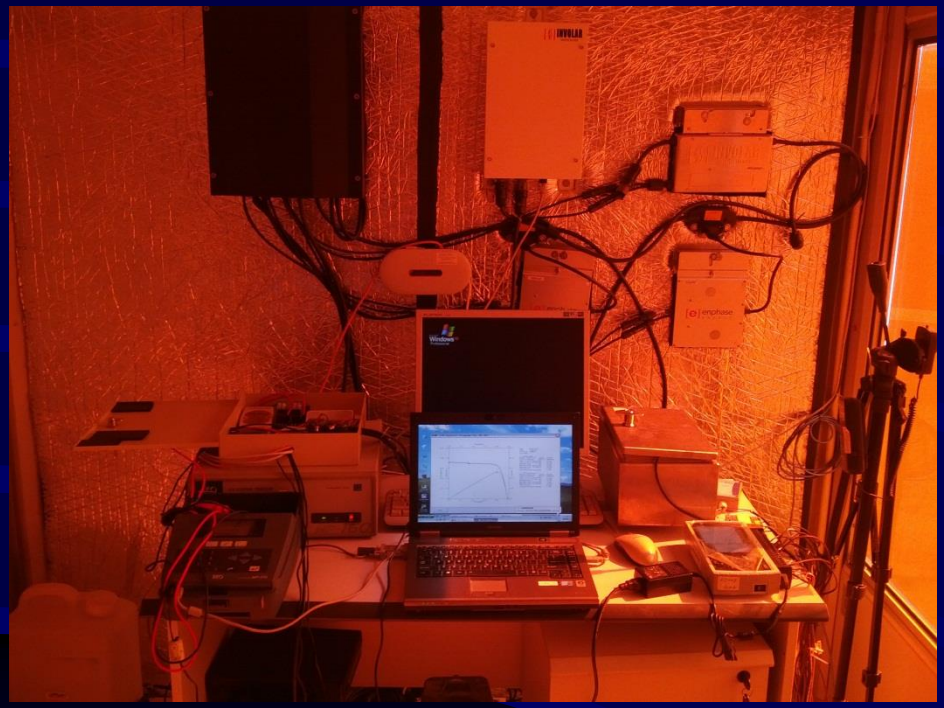


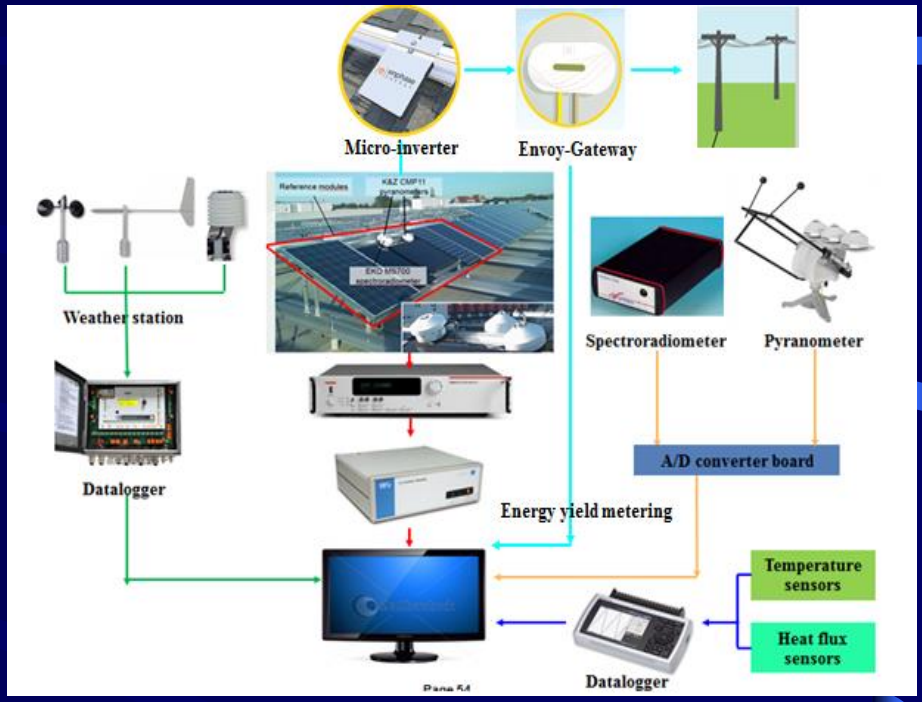


Advantages:

- ✓ Take away waste heat and reduce the operating temperature of PV modules.
- ✓ Reduce the heat gain from window and hence the energy consumption of air-conditioning.

Testing and Data Acquisition System Of BIPV Claddings



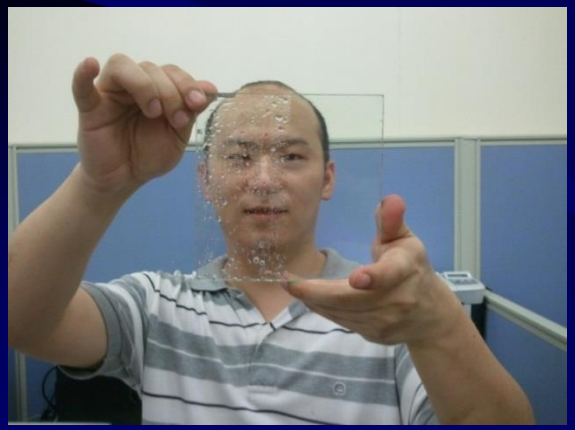


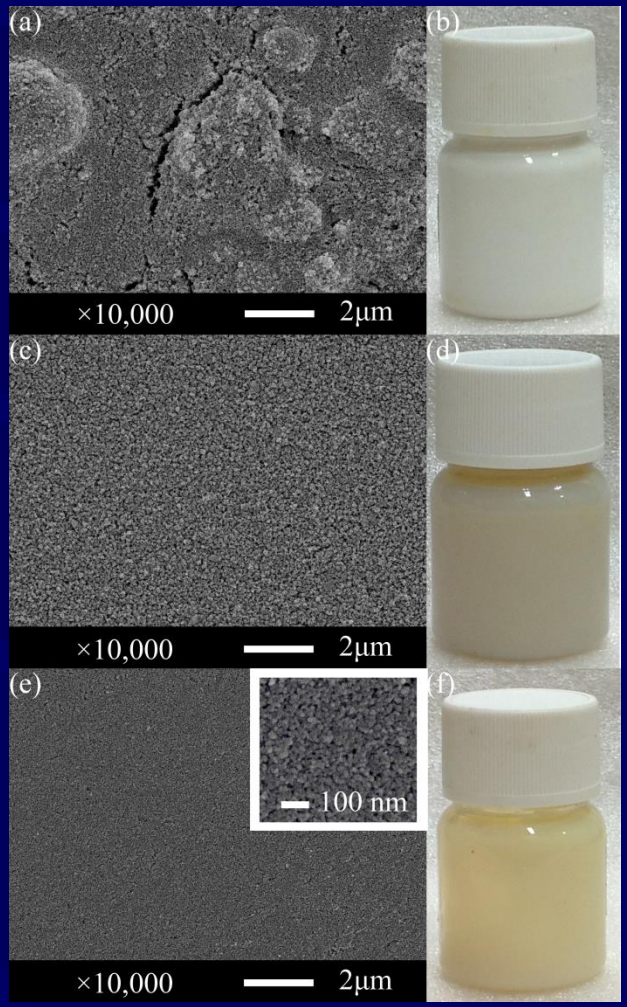
- ✓ Testing I-V curves of different PV modules simultaneously.
- ✓ Quickly switch between I-V testing state and on-grid power generation state.
- ✓ Weather data, including solar spectrum, are collected.

Superhydrophilic Self-cleaning

Nanocomposite Self-cleaning Pastes

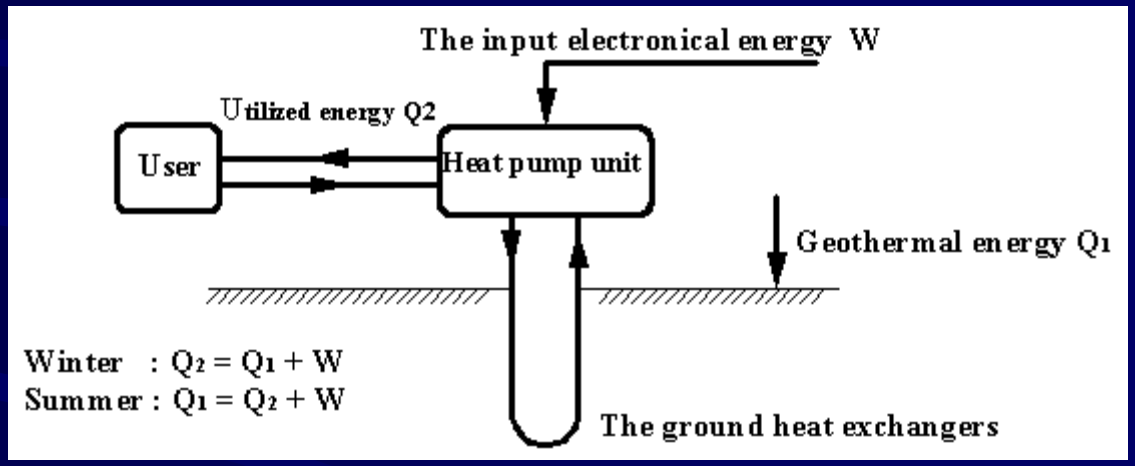
- ✓ Screen-printable self-cleaning coating
- ✓ Photocatalitic abilities and superhydrophilic self-cleaning properties
- ✓ Easy cleaning of the glass
- ✓ Cheap and facile to make





Ground-coupled Heat Pump Systems

Ground-coupled heat pump (GCHP) extracts/discharges thermal energy from/into underground in winter and summer, respectively, for space heating and cooling in buildings.

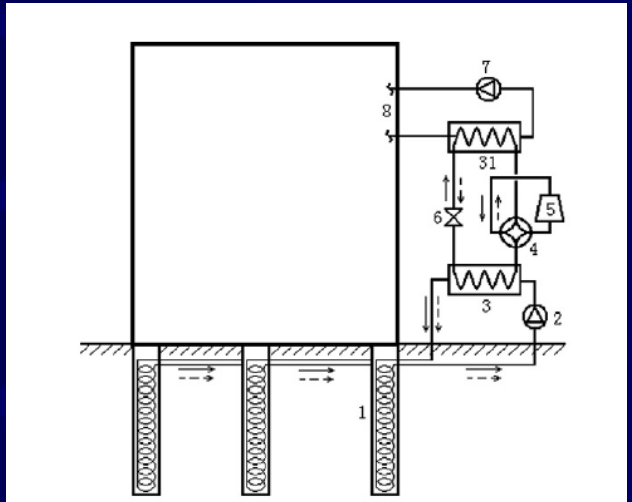


Advantages:

- ✓ Energy saving, higher COP value.
- ✓ Environmental protection.
- ✓ Aesthetical appearance; no outdoor machine.

Pile-Foundation Ground Heat Exchangers

The heat exchange tubes are buried in the piles of buildings to form an energy pile or pile foundation ground heat exchanger (PGHE) for reducing the initial cost of developing boreholes.

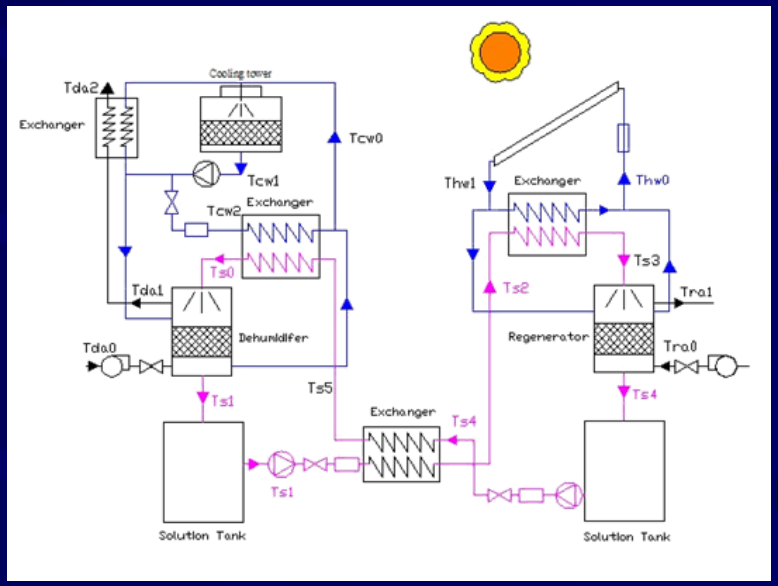


(1. PGHE; 2,7. circulation pump; 3,31. condenser and evaporator;
(2. 4. reversing valve; 5. compressor; 6. expansion valve;
(3. 8. conditioned space)

- Developing and solving the heat transfer models for PGHE.
- Investigation into the impact of groundwater flows on the heat transfer performance of PGHE.

Solar Assisted Liquid Desiccant Air Conditioning Systems

- ✓ Use solar thermal energy to regenerate the desiccant - (environment friendly)
- ✓ Handle the sensible and latent loads separately - (Energy efficient)
- ✓ Investigate heat and mass transfer during dehumidification and regeneration processes with CFD
- ✓ Simulate the dynamic operation performance



Outline

- Introduction
- Research Institute for Sustainable Urban Development (RISUD)
- Virtual construction
- Energy efficiency
- Renewable energy
- Recycling of materials
- Indoor air quality

Research on Eco-friendly Construction Materials

Research Group for Sustainable Waste Management

Group leader:
Prof. Chi-sun Poon
潘智生教授

Turning Wastes into Eco-friendly Construction Products

C&D Waste

Glass Waste

Incinerator Sludge Ash

Recycling Process

Eco-construction products

Eco-Blocks 環保磚

第一代

Recycled Aggregate

第二代

Recycled Aggregate + Recycled Glass

第三代

Recycled Glass + Recycled Aggregate + Photo-catalyst

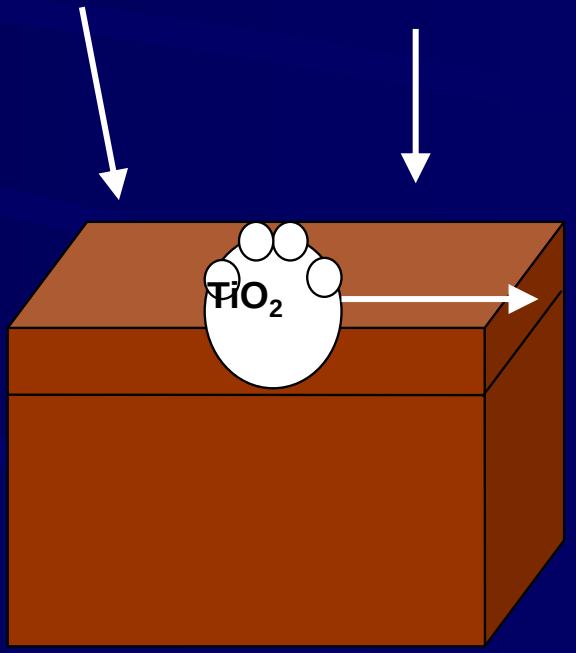
Air Pollutant Removal Paving Blocks

Eco-blocks - 3rd Generation

Sunlight

Air Pollutants (NOx)

Precipitation



Surface layer
Cement +Recycled Glass +
Recycled Aggregate + Photo-catalyst

Base layer
Cement + Recycled Aggregate +
Recycled Glass

C.S. Poon and E. Cheung. NO removal efficiency of photocatalytic paving blocks prepared with recycled materials. *Construct. Build. Mater.* **21** (8) (2006), pp. 1746-1753.
J. Chen and C.S. Poon, Photocatalytic activity of titanium dioxide modified concrete materials – influence of utilizing recycled glass cullets as aggregates, *J Environ Manag* **90** (11) (2009), pp. 3436-3442.
J. Chen and C.S. Poon, Photocatalytic cementitious materials: influence of the microstructure of cement paste on photocatalytic pollution degradation, *Environ Sci Technol* **43** (23) (2009), pp. 8948-8952.

Sequestration of CO_2 by Recycling Construction Waste

Factors affecting carbonation rate

- Pore structure
- Hydration products
- Moisture conditions
- CO_2 concentration / pressure
- Temperature

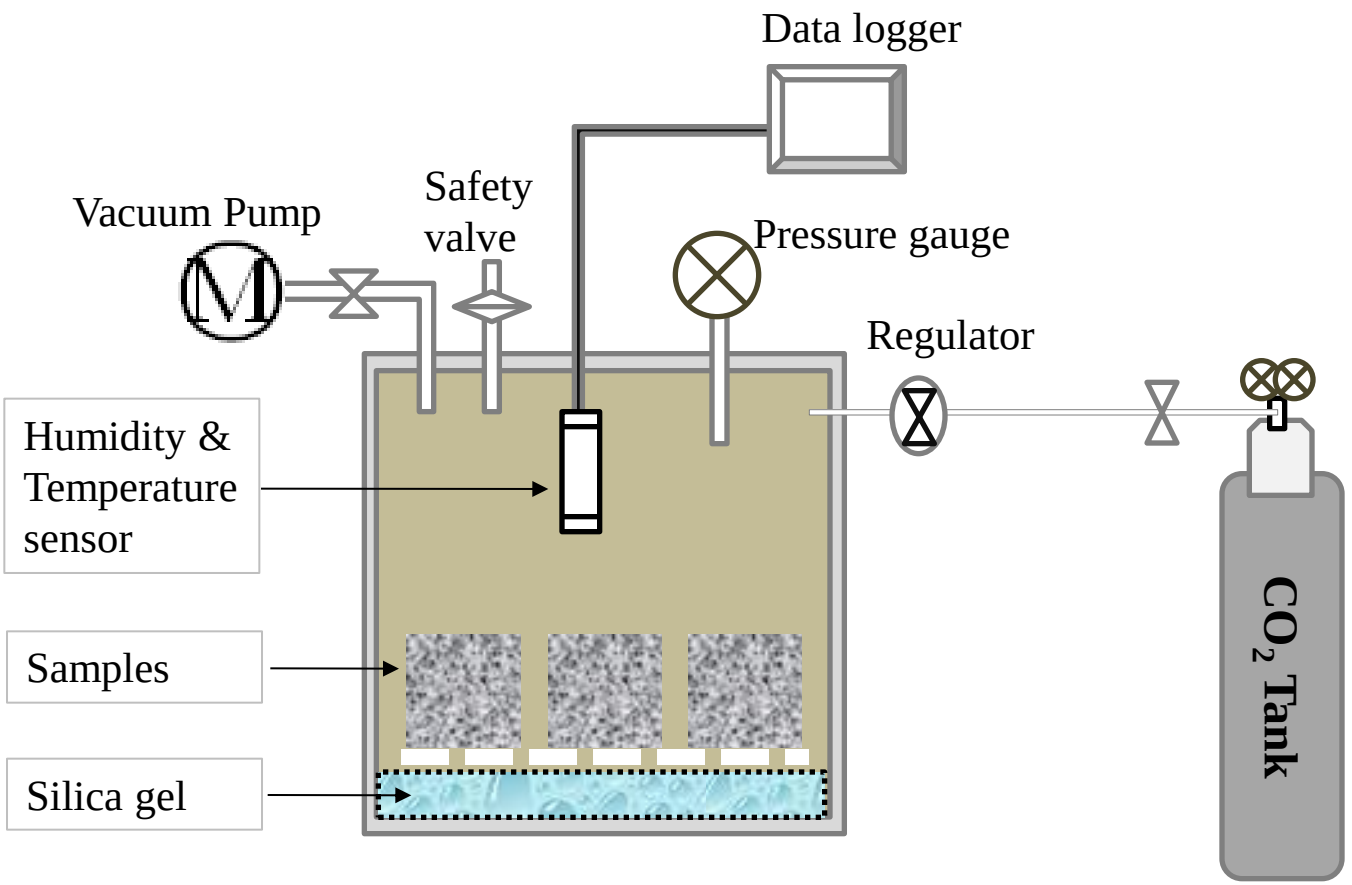
Carbonation

Effects on sample

- Capture of CO_2
- Pore densification
- Increase in strength
- Increase of weight
- Reduction in pH

Experimental Set-up

Illustration of the set-up for CO2 curing



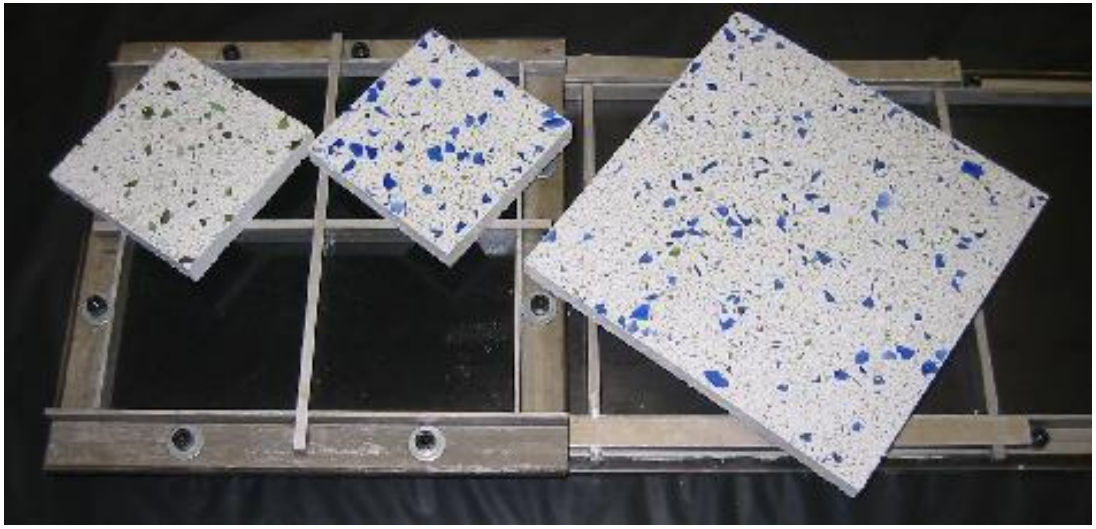
Eco-block : 4th Generation 第4代環保磚

(Recycling of Glass for Architectural Mortar)

（建築砂漿為回收玻璃）

Constituents and recycled glass were mixed in a laboratory mixer

在實驗室混合器混合成分和再生玻璃



Hardened architectural mortar with desired appearance

Research Group for Sustainable Materials and Structures

- Recycling of structural materials
- Light-weight wall panels
- Life-cycle performance of roads and structures
- Service life extension through repair and retrofit
- Durability enhancement technologies
- Light-weight/durable structures based on fibre composites
- Sustainability rating of infrastructure projects
- Impacts of climate change on infrastructure

Group leader:
Prof. Jin-Guang Teng

Elimination of Corrosion in Structures Through the Use of Composite Materials

http://www.adbengineering.com/services/structural-inspections/

UDC

中华人民共和国国家标准

P

GB 50608 – 2010

纤维增强复合材料建设工程
应用技术规范

Technical code for infrastructure application
of FRP composites

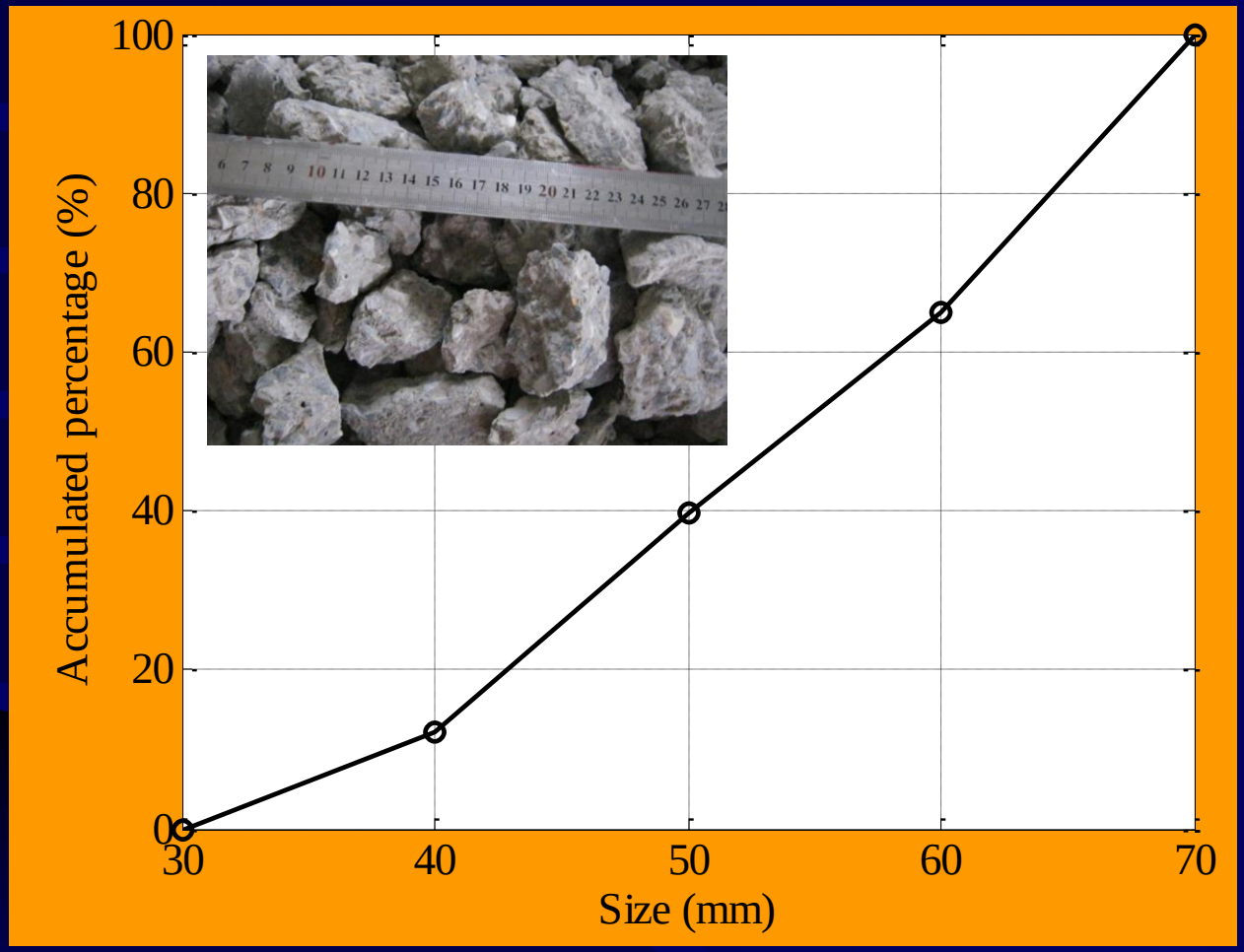
2010 – 08 – 18 发布

2011 – 06 – 01 实施

中华人民共和国住房和城乡建设部
中华人民共和国国家质量监督检验检疫总局

联合发布

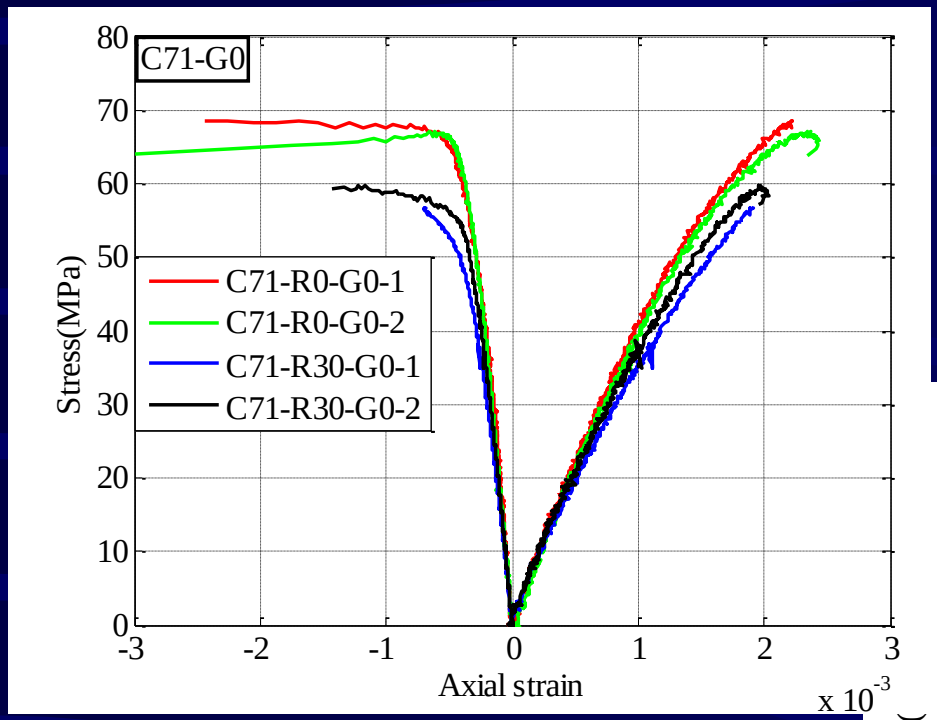
Direct Recycling of Coarsely Crushed Concrete for Structural Purposes



Size distribution of recycled concrete lumps (RCLs)

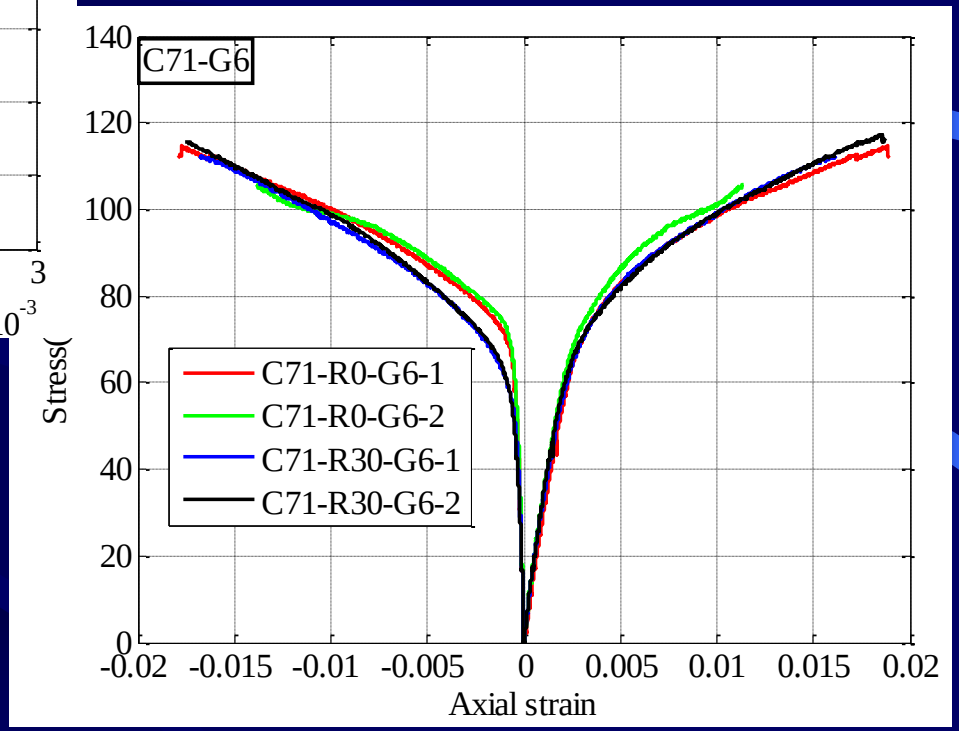
Testing of Filament Wound FRP Tubes Filled with Compound Concrete (RCLs Mixed with Fresh Concrete)

Performance of Compound Concrete



Without FRP confinement

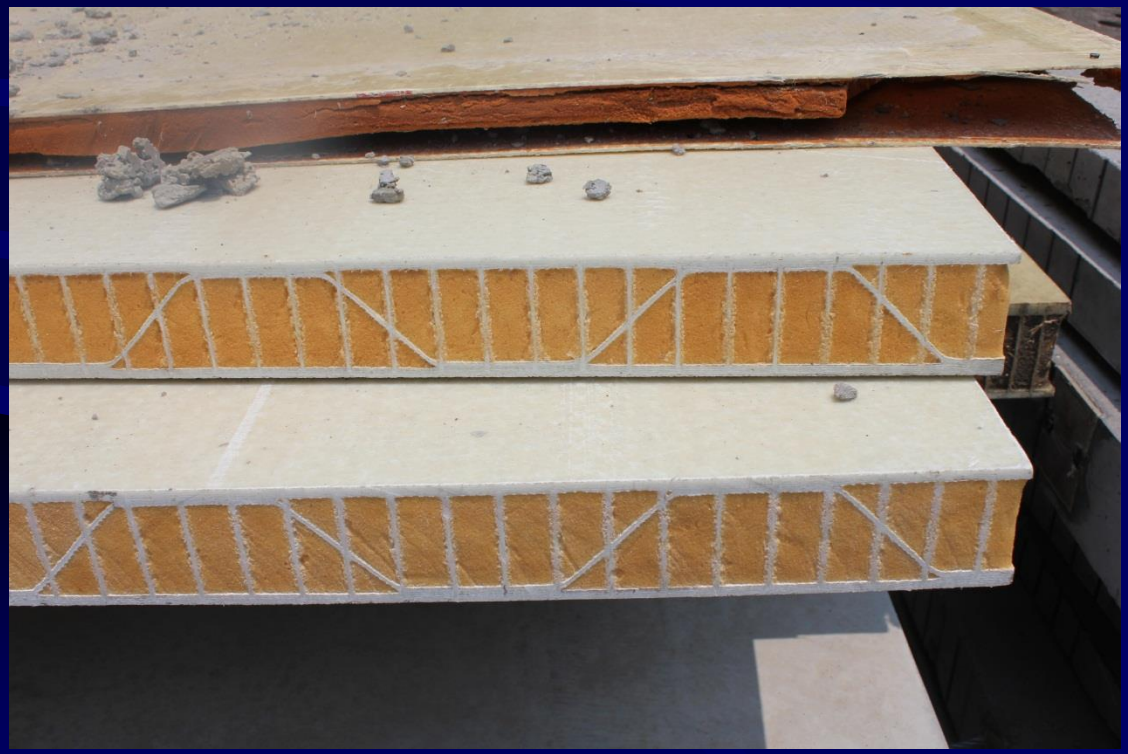
Old concrete strength:
45 to 56 MPa
New concrete strength:
71 MPa



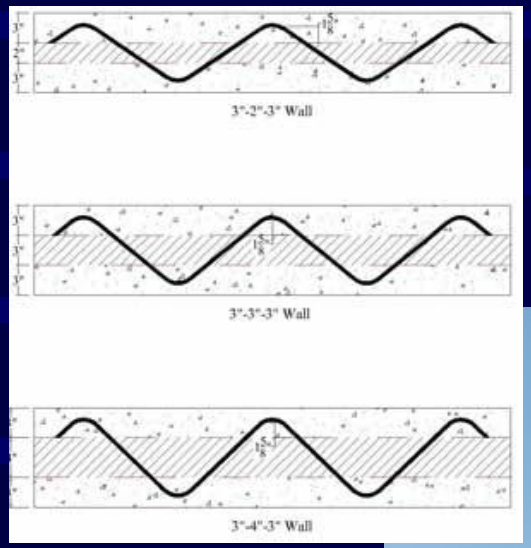
With significant FRP confinement

Sandwich Wall Panels with GFRP Skins

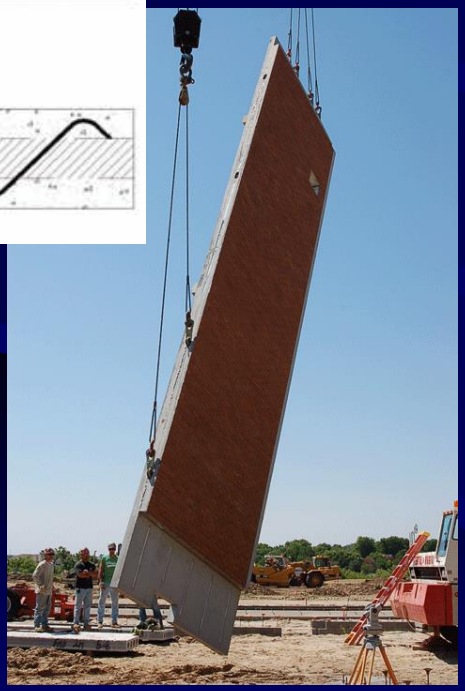
基于FRP材料的节能轻质墙面板通常采用夹心板的形式，即由内外面板（FRP）及中间的轻质填充材料（木材，聚苯乙烯泡沫和聚酯纤维材料等）组成。为保证整体性，可在FRP面板之间采用适当的连接。



Pre-cast Sandwich Wall Panel with FRP Connectors

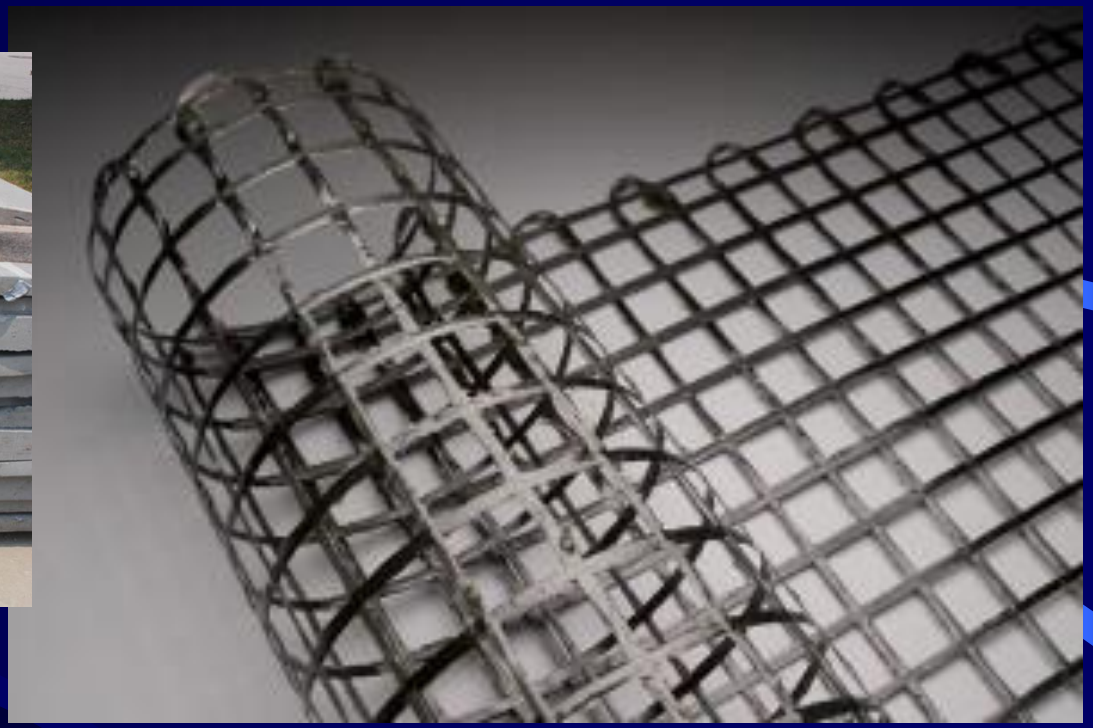


Aslan Nu-Tie
Sandwich Wall Connector



CFRP Reinforced Concrete Wall Panels

Minimization of concrete cover thickness using CFRP grids



http://www.chomarat.com/

Outline

- Introduction
- Research Institute for Sustainable Urban Development (RISUD)
- Virtual construction
- Energy efficiency
- Renewable energy
- Recycling of materials
- Indoor air quality

Research Laboratory for Indoor Air Quality (IAQ)

Group Leader:
Prof. Frank S. C. LEE

Research Interests

- Indoor pollutants emission source characterization
  - ✓ Cooking emissions
  - ✓ Incense burning
  - ✓ Tobacco smoking
- IAQ associated with building maintenance work in public areas
- Indoor secondary pollutants formation chemistry and mechanism
- Indoor odour pollution study

Study on Cooking Fumes in Hong Kong (Residential vs. Commercial)

- ✓ To conduct a full quantitative determination of the composition of residential cooking fume in Hong Kong
- ✓ To establish a baseline database of residential cooking emissions profile and characteristics that are directly relevant to conditions in Hong Kong
- ✓ To provide insight into policy relevant questions that could assist policy-makers in managing air quality in Hong Kong

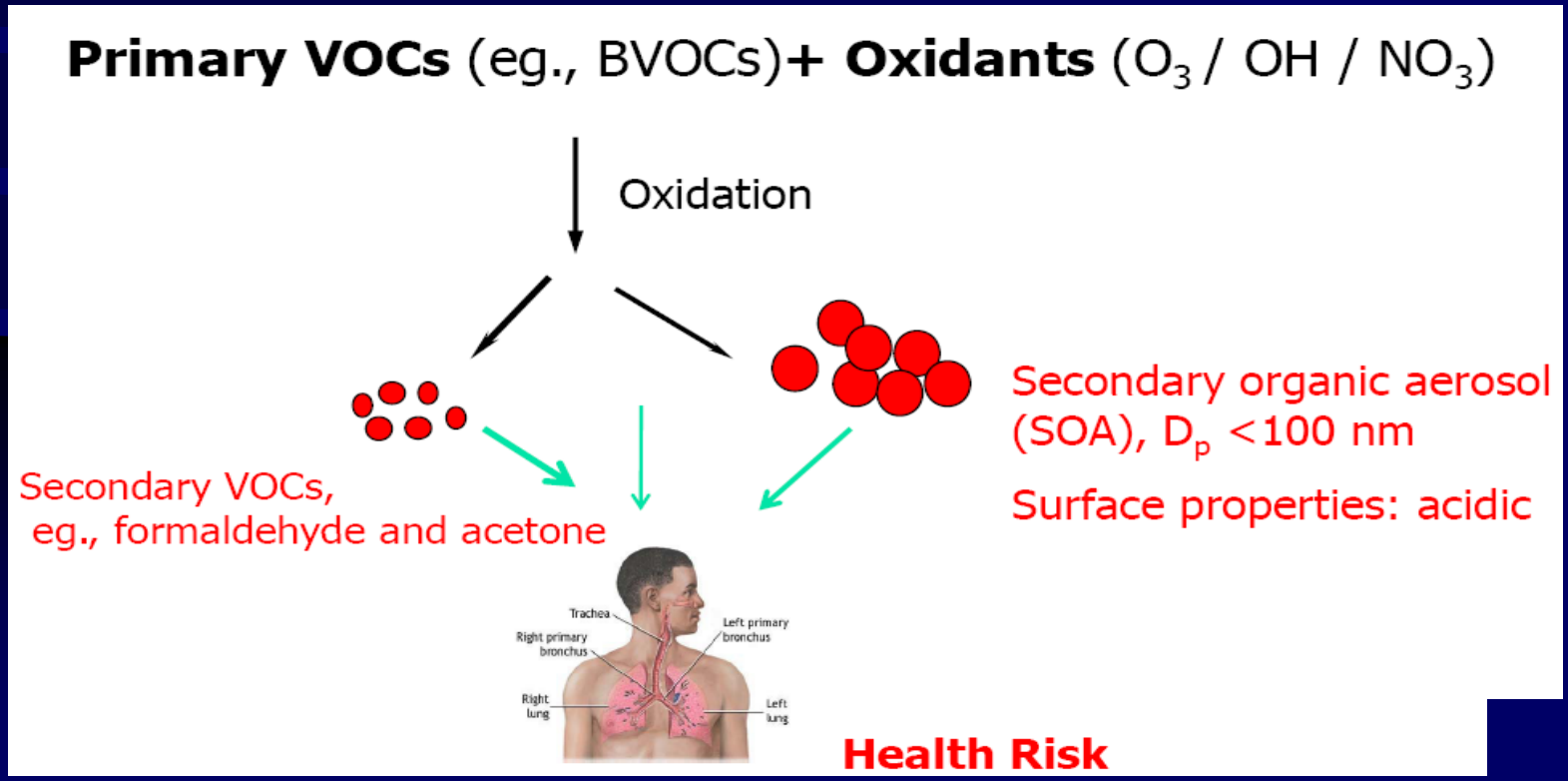
Large Environmental Chamber Study

Incense Burning Testing

Paint Emission Testing

Volatile Organic Compounds Indoors

- Volatile organic compounds (VOCs) from consumer products such as cosmetics, pesticide, cleaning agent, and Building materials: hazardous air pollutants (HAPs)
- Some of them are reactive: react easily with ozone indoors



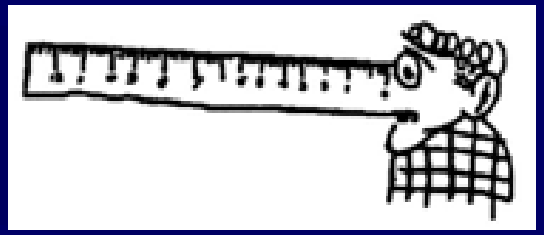
Proton Transfer Reaction Mass Spectrometer (PTR-MS)

- ✓ Very low detection limit (pptv-range)
- ✓ Real-time quantification of compounds
- ✓ Online VOC monitoring
- ✓ No sample preparation-direct injection
- ✓ 1-512 amu

The equipment is purchased by HK EPD, and is operated and maintained by Prof. S. C. Lee's group.

On-site Determination Of Odor Intensity

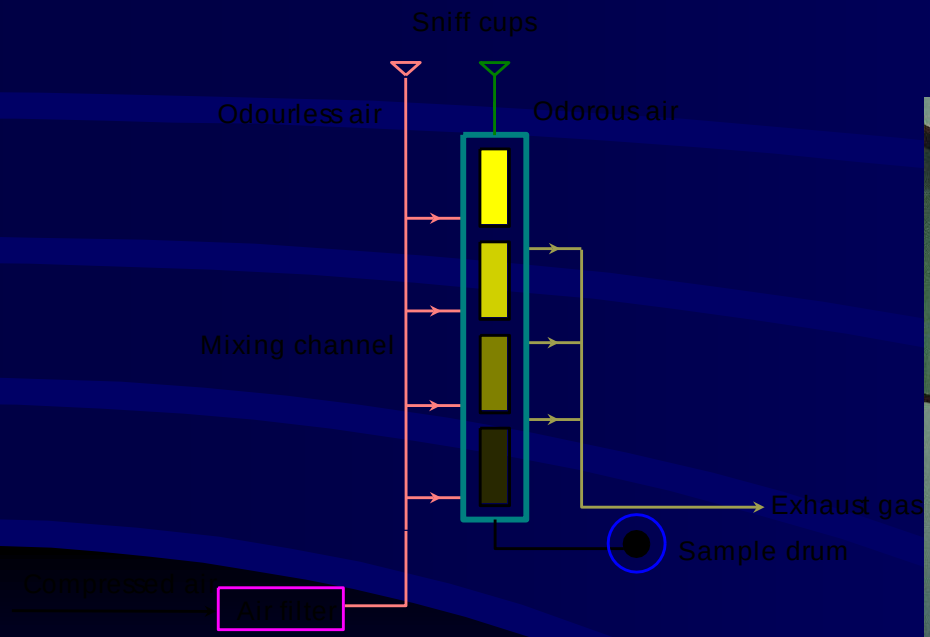
The response of an individual to an odor is directly related to the intensity at which it is experienced, where the intensity refers to an individual's perception of its strength or concentration.



Four-point scales of odor intensity used in Hong Kong

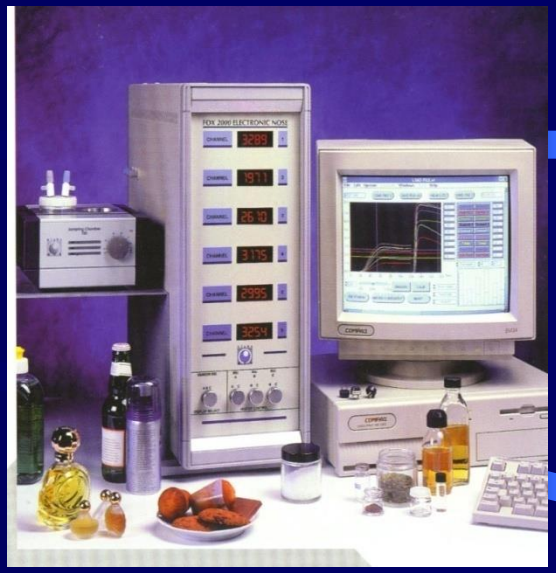
0	Not detected	No odour perceived or an odour so weak that it can not be easily characterised or described
1	Slight	Identifiable odour, slight
2	Moderate	Identifiable odour, moderate
3	Strong	Identifiable, strong
4	Extreme	Severe odour

Modern Forced-choice Dynamic Olfactometer



Electronic Nose (E-nose) Analysis

- The electronic nose is an instrument to detect volatile chemicals or categories of chemicals and then uses the information to predict sensory-like properties.
- Electronic noses contain an array of sensors (sintered metal oxides, catalytic metals, conducting polymers, lipid layers, phtholocyanins, organic semi-conductors, surface acoustic wave or combinations) which respond to a wide variety of chemicals.
- All of these sensors (and their combinations) vary in the magnitude of response to any one compound giving them the discriminatory ability required to analyze odors
- Response data are exported to a computer which has been trained to use chemometric and "artificial neural network" computer software as a way to recognize the pattern of a mixture of compounds as a specific odor and to discriminate slight differences.



Thank you for your attention!

I wish you all a very happy and fruitful time in Hong Kong!